Micro-grids Role in Powering Critical Loads During Extreme Events

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Introduction

» US Grid's availability is about 3 nines = 8 outage hr/year

» An availability of 3 nines is too low for many applications with critical loads (e.g., information and communication technology centers).

» Utility distribution metrics do not account for long outages occurring during storms. E.g. IEEE Standard 1366-2003 reads: "*activities that occur on major event days should be separately analyzed and reported.*"

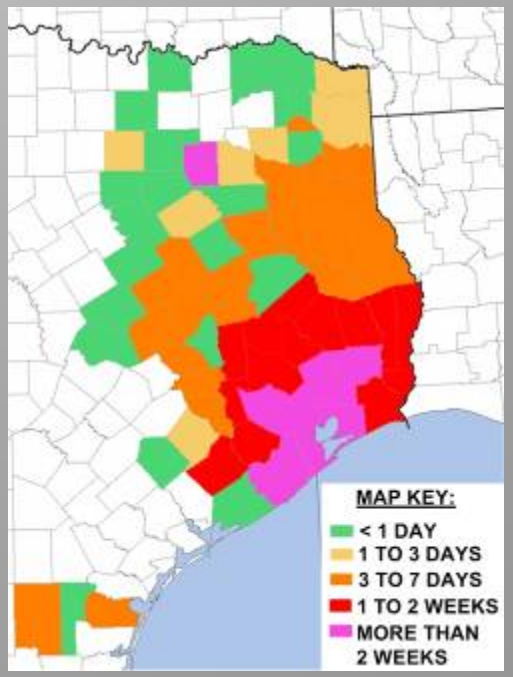
» Hurricanes and earthquakes often originate extensive outages both in terms of geographical location and duration.

» Power grid vulnerability to extreme events is a significant issue for all loads, critical and non-critical (e.g. common residences)

» Are there power supply approaches that are more resistant to extreme events than others? If yes, which ones are those options?

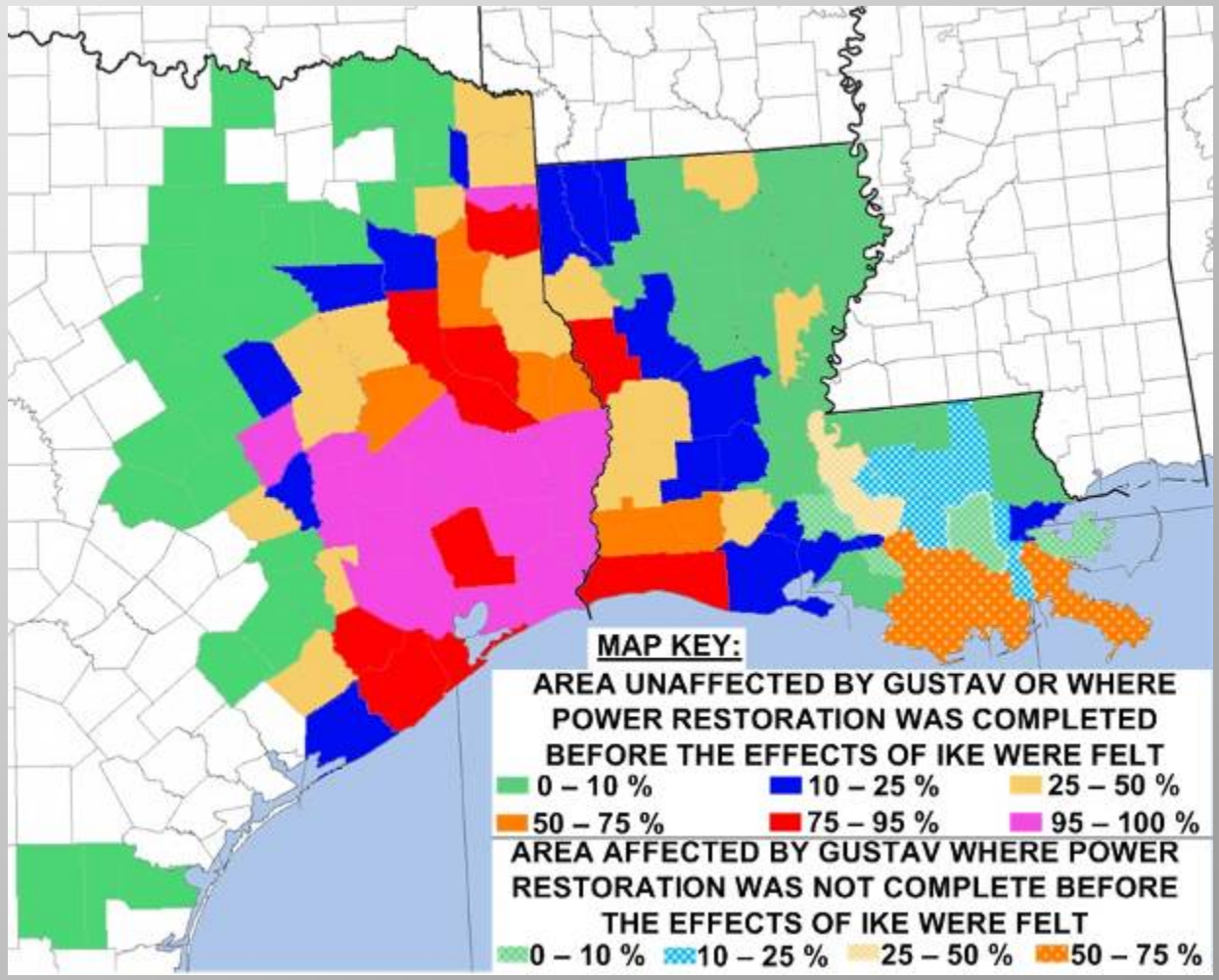
Grid's behavior during disasters

- Power supply issues during disasters is a grid's problem transferred to the load.
- Power grids are extremely fragile systems and their failure is one of the most important causes of other critical services outages during extreme events.



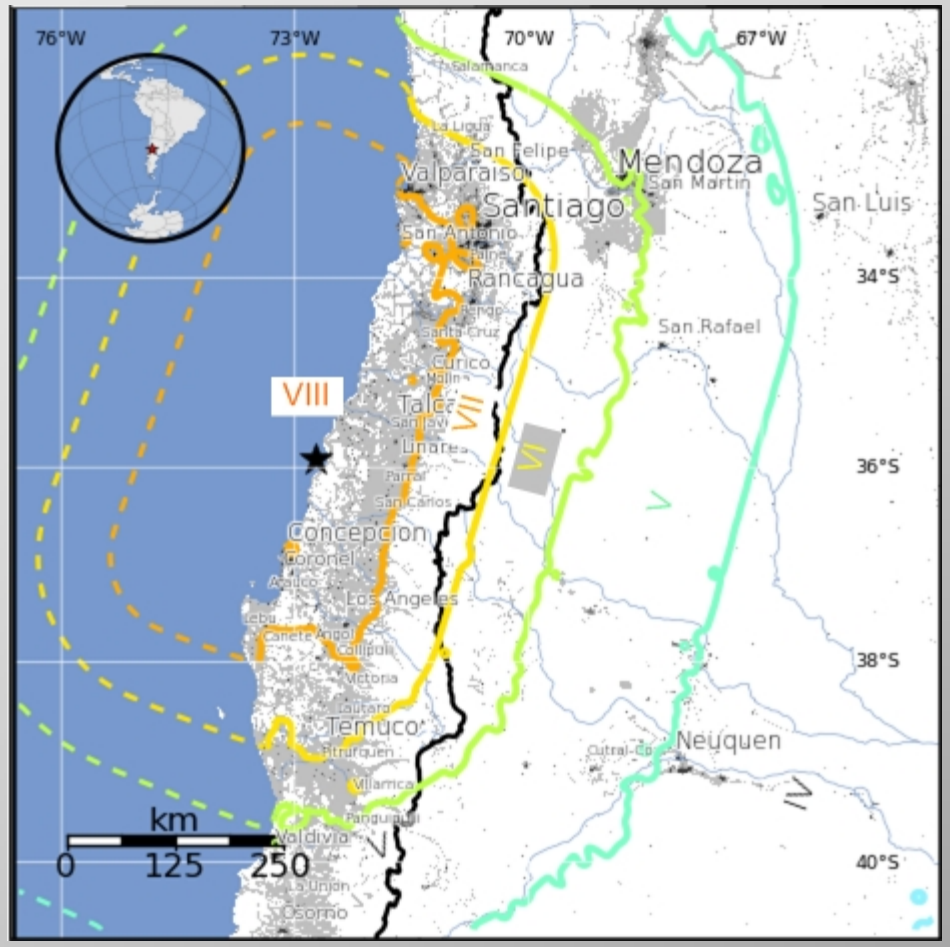
Power Grids Fragility

» Hurricane Ike: little damage caused very high outage incidence (areas with 1% of damaged infrastructure lost all power)



Power Grids Fragility

» Earthquakes (and tsunamis) seem to show the same pattern in terms of damage than hurricanes.



USGS

Grid's behavior during disasters

» Common concept of damage to the electric grid during disasters:

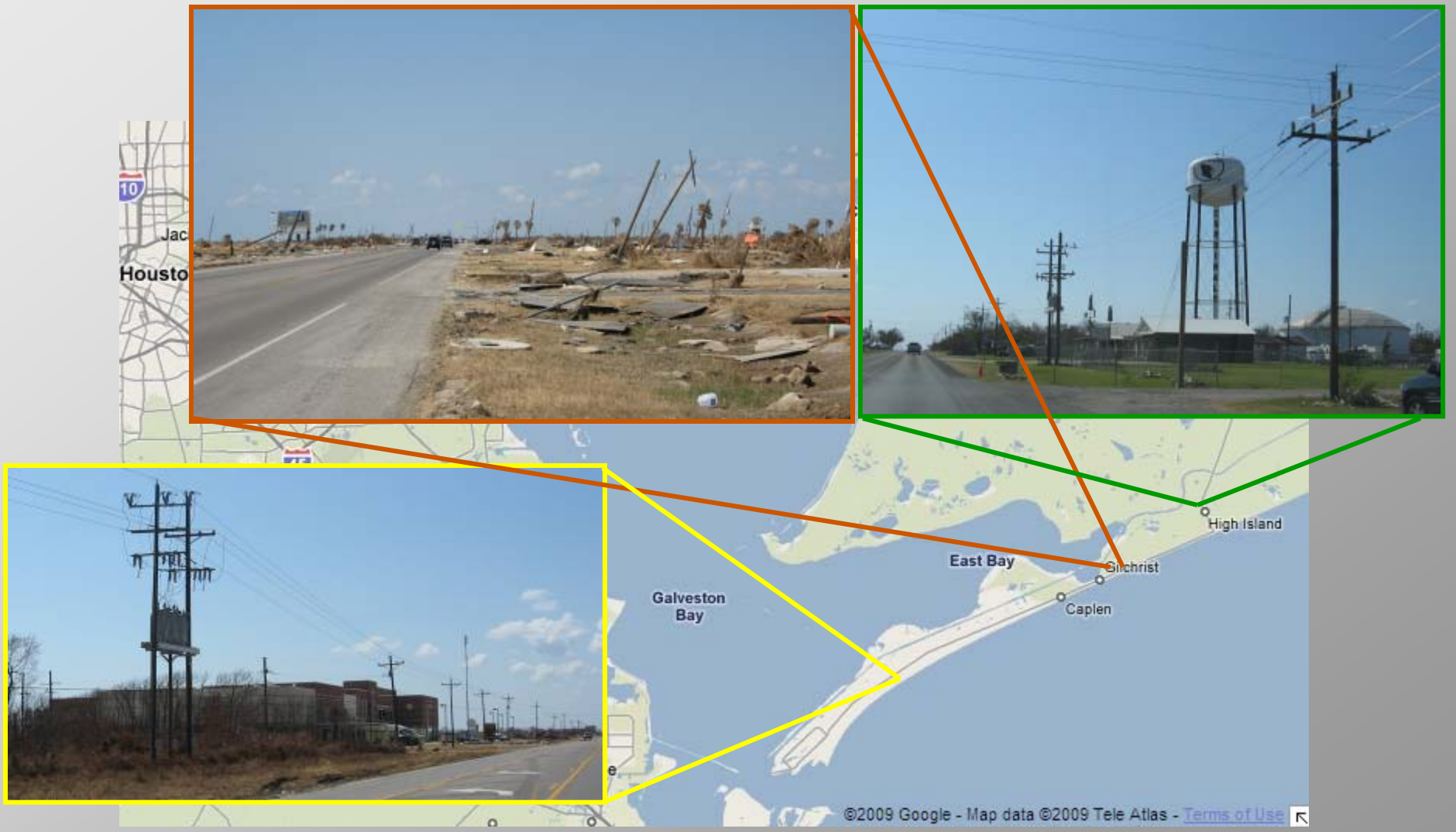
» Real sustained damage in more than 90 % of the area:

Effects of Extreme Events on Power Grids

- Some myths:
  - The electric grid is a very reliable system.
  - Power grids fail during hurricanes or earthquakes because of nature's tremendous power. During these disasters significant portions of the power grid is damaged. Hence, little can be done to prevent outages and the best strategy is to wait for the system to fail and then repair it.
  - All portions of a power grid (generation, transmission and distribution) experience similar degree of damage.
  - Other critical infrastructures fail because their system components fail.
  - Effects of disasters on all infrastructures is more or less the same.
  - Most of the damage is caused by hurricane's intense wind or earthquake shacking.

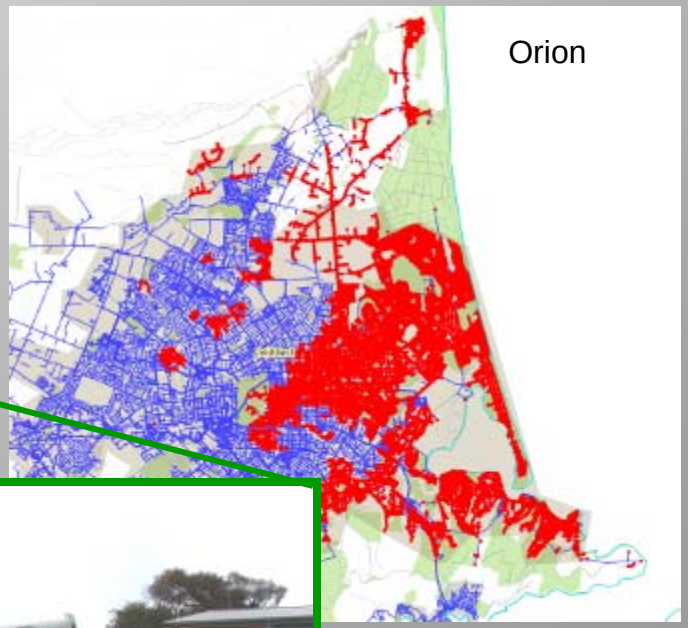
Extreme events Damage

» Hurricane damage distribution is inhomogeneous



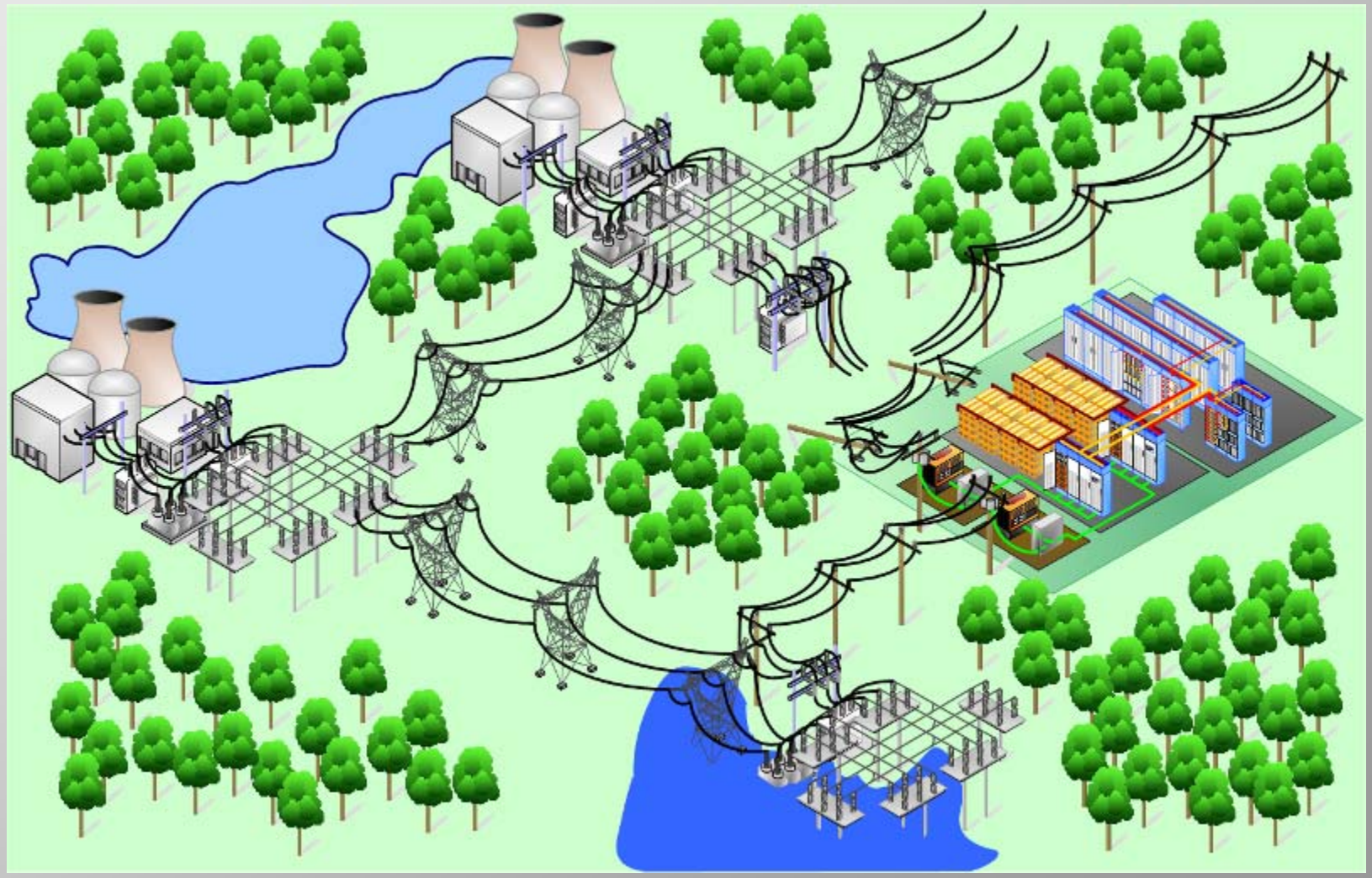
Extreme events Damage

» Earthquake damage distribution is inhomogeneous, too: it affects mostly at sub-transmission and distribution levels where damage depends on construction practices, terrain, and disaster characteristics.



Power Grid Diversity?

» Two power paths imply redundancy, not diversity



Power Grid Redundancy

» Sub-transmission and distribution portions of the grid lack redundancy

Availability issues in power grids

» Power grids availability issues:

- Centralized control
- Operation coordination over extensive area
- Aging components
- Insufficient or inhomogeneous infrastructure distribution (leading to insufficient generation and/or transmission congestion points)
- Lack of active elements in transmission and distribution portions
- Lack of diverse power alternatives (ultimately, there is only one grid)
- Lack of redundancy in sub-transmission and distribution paths
- Higher penetration of advanced loads, such as PHEVs will aggravate availability issues

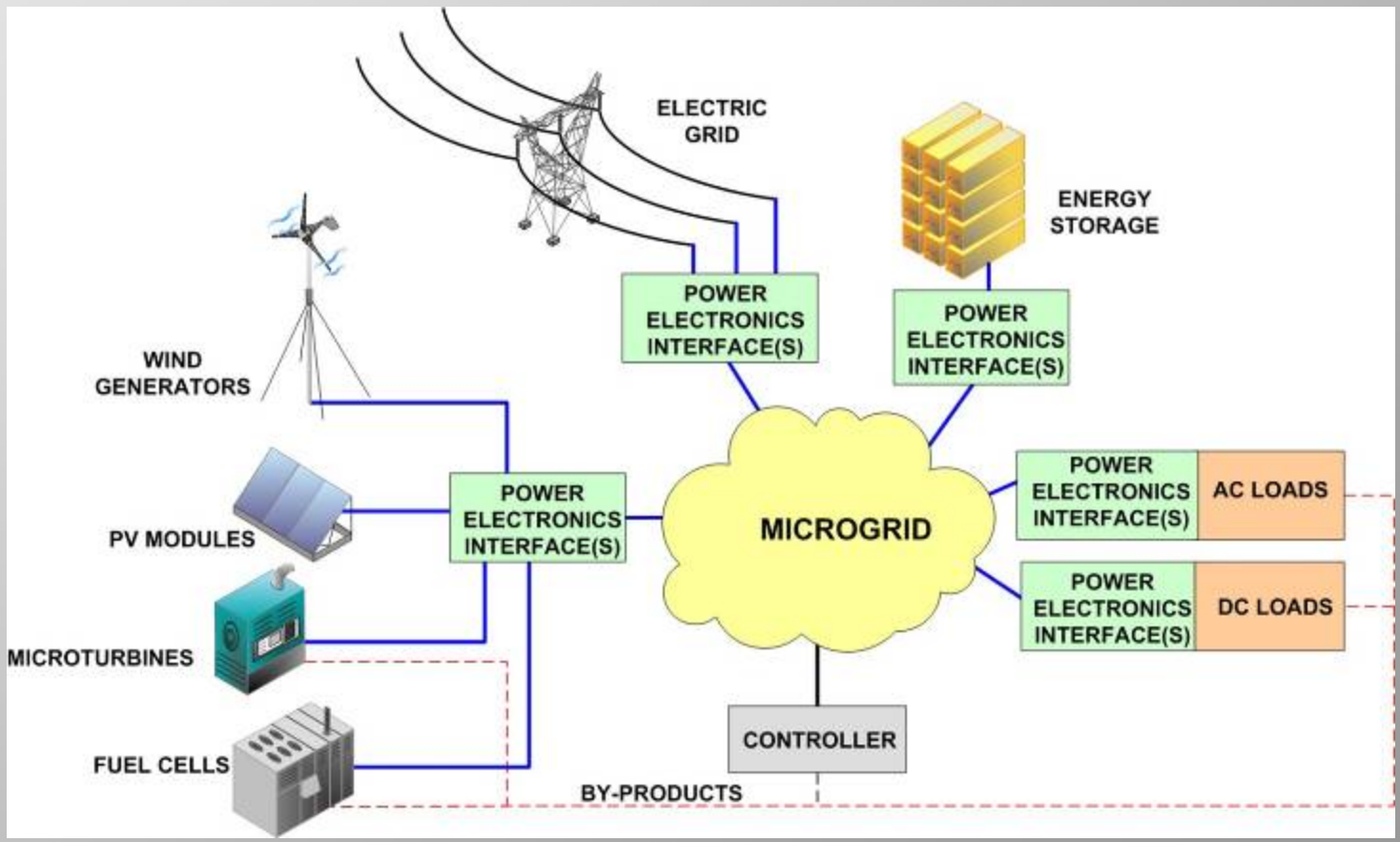
Highly available power during disasters

» Power electronic enabled micro-grids may be the solution to achieve reliable power during disasters (e.g. NTT's micro-grid in Sendai, Japan)

Micro-grids

» So, what is a micro (or nano) grid?

»Microgrids are independently controlled (small) electric networks, powered by local units (distributed generation).



Micro-grids

- Fundamental concepts

» Local power generating units are the primary power source.

» The ac utility grid is an auxiliary source of power.

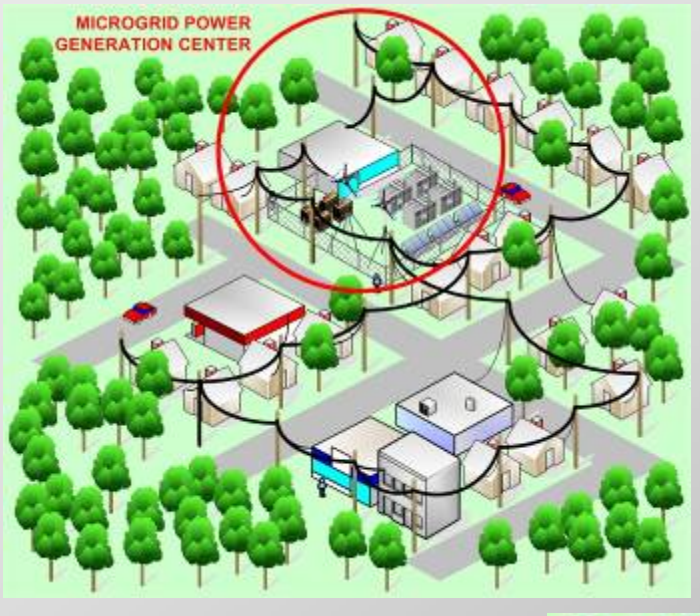
» Traditional architectures are energy-based systems whereas microgrid-based systems are power-based systems.

» Microgrid-based systems require much less energy storage to achieve the same availability than conventional backup power plants.

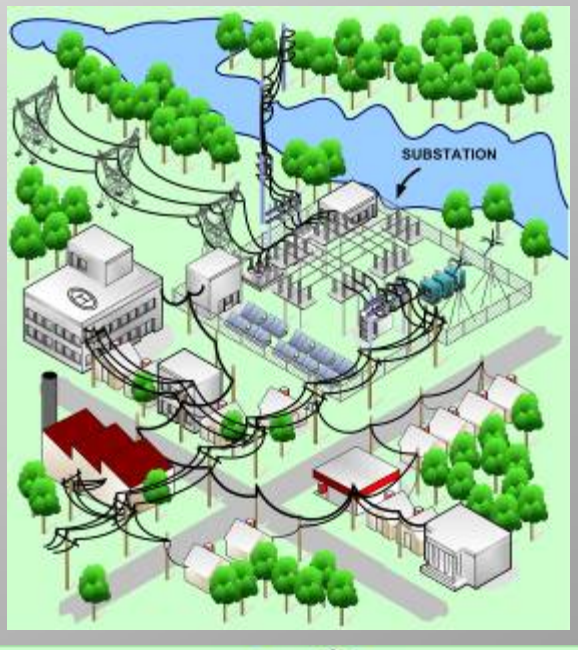
» Well designed microgrids can exceed 5-nines availability but only with diverse power sources

Planning for enhanced power availability

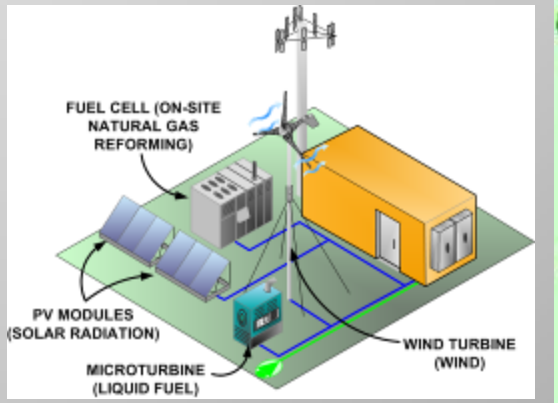
» Because of high costs micro-grids may only be suitable for critical loads.



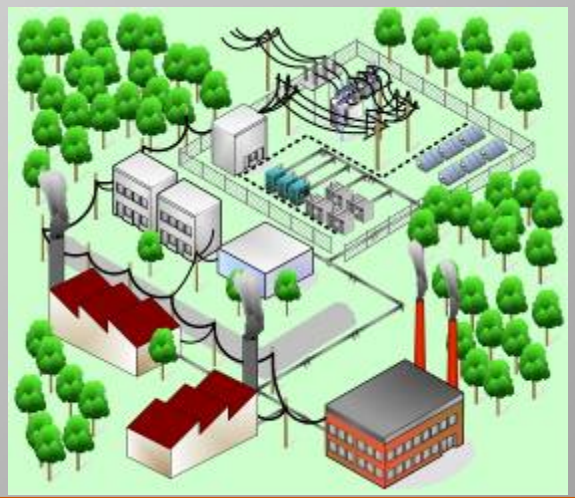
DIFFERENTIATED POWER QUALITY CIRCUITS



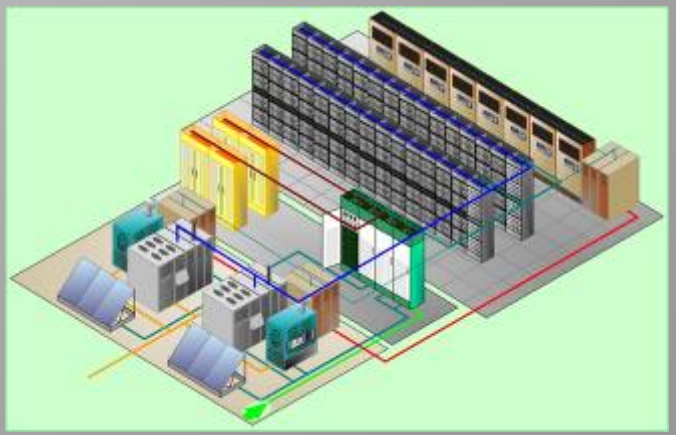
CELL SITE



NEGHBORHOOD MICRO-GRID WITH REDUNDANT DC DISTRIBUTION PATHS



INDUSTRIAL COMPLEX



DATA CENTER

Planning for enhanced power availability

» Sustainable systems, in the sense that they endure, are resilient systems.

» Higher efficiency, and less volume and footprint also supports resiliency.

» Distributed generation leads to a de-centralized control architecture.

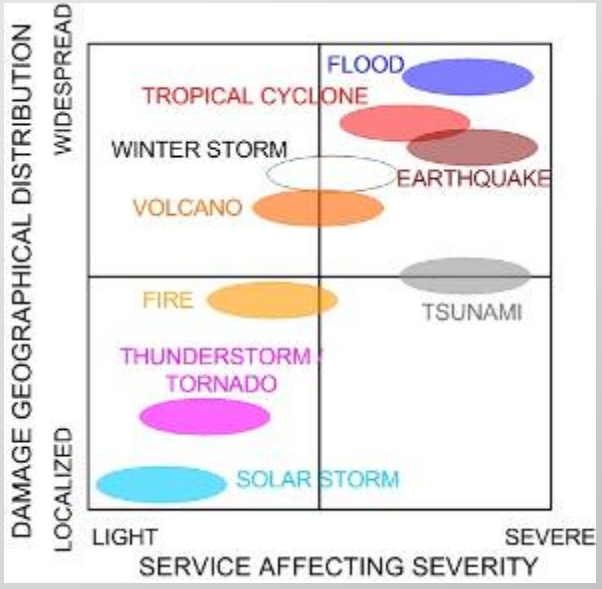
» Distributed generation adds active elements which support independent control strategies.

» Micro-grids require diverse power inputs because each distributed generation techno-logy has worst availability than the grid.

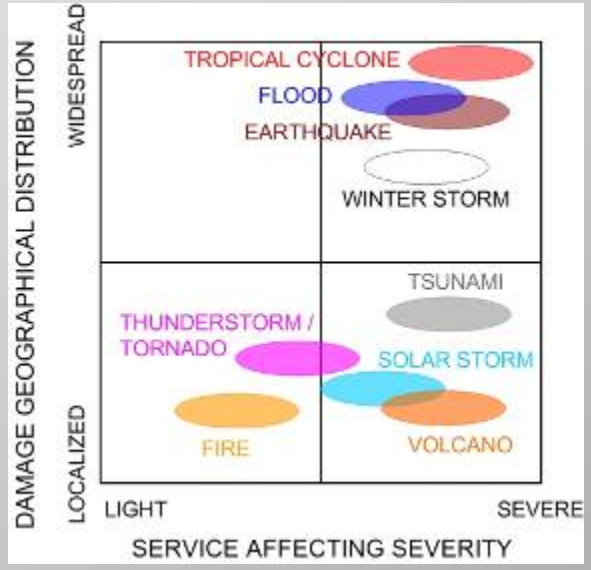
Power supply units	Fuel / source of energy	Availability *a*
Genset (operation time< 2 hours) Fail to start probability: 0.0241	Diesel / Natural gas	0.9939
Genset (operation time > 24 hours) Fail to start probability: 0.0241	Diesel / Natural gas	0.85
PV generation system*	Solar energy	0.996
PEM Fuel Cell	Hydrogen / Natural Gas	0.967742
Microturbine	Natural Gas / Propane / liquid fuels	0.993789
Wind turbine*	Wind	0.9595

Planning for enhanced power availability

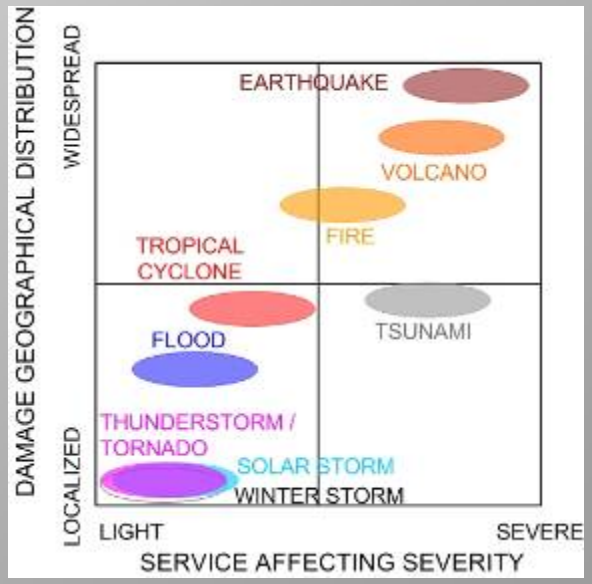
» When planning for diverse power input, we need to considered that extreme events affect infrastructures (lifelines) differently.



Transportation and fuel delivery



Electric grid

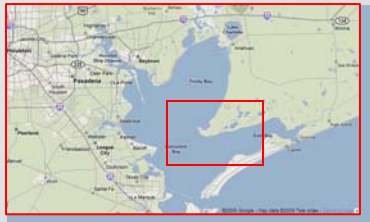


Natural gas

» Renewable sources (inherently dc) are less affected by most disasters than other infrastructures. But their output is variable.

Planning for enhanced power availability

» PV modules survival to hurricanes



Planning for enhanced power availability

» PV modules and wind generators survival to earthquakes and tsunamis

Additional issues with Renewable and Alternative Sources

• Large footprints, dispatchability, intrinsic characteristics (e.g. voltage levels), costs, and others issues limit their application.
• Power electronics (e.g. multiple-input converters) and energy storage mitigate these issues.